AN INVESTIGATION OF AIRCRAFT
MANEUVERABILITY AND AGILITY

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13. ABSTRACT (Maximum 200 words) Improved effectiveness of close air support (CAS) aircraft has increased counter-air developments and the possibility of air-to-air combat (ATAC). Maneuverability and agility are desired attributes of CAS aircraft which must operate close to terrain or engage in air combat. The objective of this thesis was to investigate maneuverability and agility of modern CAS aircraft. The investigation was accomplished by expanding the capabilities of HELCOM to incorporate fixed wing aircraft modeling. HELCOM is a series of computer programs which use energy/force balancing methods to determine maneuverability and agility parameters. Joint Air Attack Team (JAAT), integrating OH-58D, AH-64A, and A-10A aircraft, served as the CAS air force for investigating maneuverability and agility. HELCOM, as a tool for understanding maneuverability and agility, was improved to provide a good approximation for both rotary wing and fixed wing aircraft. Tilt-rotor aircraft concept was compared to current CAS aircraft and shown to incorporate design features desired in highly maneuverable and agile aircraft.

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LIST OF SYMBOLS

α	angle of attack
AR	aspect ratio
Cd	coefficient of drag
Cdo	zero lift drag coefficient
Cl	coefficient of lift
Clmax	maximum lift coefficient
D	drag
e	Oswald efficiency factor
L	lift
M	Mach number
ρ	density
S	reference area
T	thrust
V	velocity
W	weight

Subscripts

c	compressible
cl	climb
i	incompressible
man	maneuver

LIST OF ABBREVIATIONS

deg	degree
ft	feet
g	gravitational acceleration
km	kilometer
ktas	knots true airspeed
lbs	pounds
m	meter
min	minute
sec	second
shp	shaft horsepower

LIST OF ACRONYMS

ATAC	Air-to-Air Combat
CAS	Close Air Support
FLOT	Forward Line of Own Troops
FOV	Field of View
HELCOM	Helicopter Combat Computer Programs
JAAT	Joint Air Attack Team
M&A	Maneuverability and Agility
MGW	Maximum Gross Weight
NOE	Nap-of-the-earth
PDW	Primary Design Weight
SEP	Specific Excess Power

SUMMARY

Integration of all forces on modern battlefields has resulted in development of the Joint Air Attack Team (JAAT) to provide close air support (CAS). JAAT is the operational integration of CAS air forces, combining both helicopters and airplanes into an effective fighting team. A similar, integrated approach should be used for investigating future CAS design options. Improved effectiveness of CAS aircraft has increased counter-air developments and the possibility of air-to-air combat (ATAC) within the low altitude air war. Maneuverability and agility are desired attributes of CAS aircraft which must operate close to terrain to survive or may be required to engage in air combat. The objective of this thesis was to investigate maneuverability and agility of current CAS aircraft. The investigation was accomplished by expanding the capabilities of HELCOM to incorporate fixed wing aircraft modeling. HELCOM is a series of computer programs which use energy/force balancing methods to determine helicopter maneuverability and agility parameters.

Fixed wing modeling was accomplished using force balance methods and verified using A-10A airplane data. An OH-58D helicopter model was also incorporated and verified. JAAT, integrating OH-58D, AH-64A, and A-10A aircraft, served as the CAS air force for investigating maneuverability and agility. HELCOM, as a tool for understanding maneuverability and agility, was improved to provide a good approximation for both rotary wing and fixed wing aircraft. Tilt-rotor concept was compared to current CAS aircraft and shown to incorporate design features desired in highly maneuverable and agile CAS aircraft.

Chapter I

INTRODUCTION

1.1 Motivation

A primary role of aircraft in combat is to provide close air support (CAS) for ground forces. The success of the CAS mission is of immediate importance to the AirLand Battle commander who must integrate all available forces to seize the objective. Integration of all air forces has resulted in utilizing both Air Force CAS airplanes and Army CAS helicopters to neutralize immediate battlefield threats. The functional integration of air assets on an operational level suggests an integrated approach be used when investigating technologies and aircraft designs for the CAS mission.

Political climate has not altered the threat environment in which CAS aircraft will operate nor the variety of missions. CAS aircraft may be required to operate against only small arms fire or against a dense array of highly lethal air defense systems. The high lethality and ready availability of modern air defense weapons has forced development of tactics which maximize the use of terrain for survivability. The requirement to avoid detection using terrain flight techniques has resulted in an emphasis on maneuverable and agile aircraft. The success of detection avoidance through terrain flight techniques coupled with an increase in number of aircraft devoted to the battle area has given rise to the possibility of chance encounters with enemy aircraft. Consequently, the possibility of air-to-air combat (ATAC) with enemy CAS aircraft or enemy aircraft specifically designed to counter the CAS mission exists. Terrain flight and counter-air requirements emphasize the increasing need for a highly agile and maneuverable aircraft.

1.2 Previous Work

Significant efforts have been made to understand ATAC within the low altitude air war. Employment considerations for helicopter ATAC have been examined by Cox and Roy [Ref 1], Bowman [Ref 2], and Throckmorton [Ref 3].

Simulations of ATAC have been conducted by Decker [Ref 4] for tilt-rotor aircraft. Important design considerations have previously been investigated by Lappos [Ref 5] and Olson and Scott [Ref 6].

To investigate maneuverability and agility (M&A) a series of helicopter computer programs were developed to predict rotorcraft M&A parameters. Combined efforts of Georgia Institute of Technology, U.S. Army Aviation Systems Command (AVSCOM), and Flight Systems, Inc. (FSI) developed a series of helicopter computer programs (HELCOM) [Ref 7]. The goal was to provide a quick comparison of capabilities between helicopters in an air combat situation. HELCOM I,II, and III combined to compute M&A parameters using energy/force balance methods and to provide a method for comparison of various rotorcraft designs.

1.3 Objective

The objective was to investigate maneuverability and agility of current CAS aircraft.

Chapter II

COMPUTER MODELING

2.1 HELCOM I

HELCOM I was the first of a series of computer programs designed to predict helicopter M&A. In this program values of helicopter performance parameters are computed as a function of speed, altitude, weight, configuration, and power setting. Input data are basic airframe, engine and rotor characteristics. Output data are presented in speed versus density altitude matrix format. Key output parameters of HELCOM I are

- maximum rate and angle of climb
- maximum longitudinal acceleration
- maximum sustained load factor and turn rate
- minimum sustained turn radius
- maximum transient load factor and turn rate
- minimum transient turn radius
- longitudinal deceleration during transient turns

maximum power off deceleration

maximum level attitude deceleration

power off descent rate and angle of descent

maximum stabilized dive rate and angle of descent

maximum gross weight for hover

maximum level flight speed

HELCOM I used a force balance method to compute desired output. The helicopter is quasistatically trimmed in various flight conditions using an iterative approach to change fuselage angle of attack and pylon tilt until horizontal and vertical forces are balanced. The rotor mathematical model is based upon a nonlinear closed form solution to the combined axial momentum and blade element theory. Average rotor lift and drag coefficients are used in rotor power predictions. Parasite drag calculated from equivalent flat plate drag of the fuselage, pylon, and wing are summed with rotor requirements to obtain total vehicle power required. A first order response using time constants is incorporated for initial acceleration prediction. Results obtained from HELCOM I have previously been correlated with flight test data for AH-1, UH-1, CH-3, and

AH-64A helicopters [Ref 7].

HELCOM I was modified to incorporate the capability to predict M&A parameters for subsonic fixed wing aircraft. No moment balance or stability derivative calculations were incorporated. An energy/force balance approach was used. The aircraft was considered a point mass with horizontal and vertical degrees of freedom. Lift, drag, propulsive, and gravitational forces were trimmed in various flight conditions using an iterative approach to change fuselage angle of attack until forces were balanced. Summing forces normal and parallel to the wind axis yielded the following equations for level unaccelerated flight:

$$L - W + T\sin\alpha = 0$$

$$T\cos\alpha - D = 0$$

Prandtl-Glauert compressibility correction factor was applied to the average lift coefficient calculation.

$$Cl_c = Cl_i/(1-M^2).5$$

A parabolic drag polar was assumed for average drag coefficient calculation.

$$Cd = Cdo + Cl^2/\pi\ e\ AR$$

Propulsive force contribution to the vertical force opposing gravity was retained for computations. Stall speed was determined from the following equation:

$$Vstall = [2(W - T\sin\alpha) / \rho * S * Clmax]^{.5}$$

Thrust available was represented by a turbofan engine model with corrections applied for installation and bleed losses, ram effect, and temperature and pressure variations presented in McCormick [Ref 8].

A more detailed explanation of force balance methods and the applicable equations of motion are presented in References 9 and 10. The fixed wing model was correlated with flight test data available for the A-10A airplane [Ref 11]. Further HELCOM modification included incorporating the OH-58D helicopter model and verifying results with flight test data [Ref 12]. Figures 1 through 4 are presented to show a comparison of flight test data with HELCOM generated data for the A-10A and OH-58D aircraft models.

2.2 HELCOM II

HELCOM II program provided comparison of key performance parameters between two aircraft or one aircraft in two configurations. Results are presented in speed versus density altitude matrix format. Comparison calculations are performed by subtracting values of output parameters obtained in HELCOM I. No modification of HELCOM II was accomplished during this investigation of CAS aircraft.

2.3 HELCOM III

HELCOM III was the final computer program which utilized output M&A parameters of HELCOM I in a series of timed maneuvers. These maneuvers, summarized in Table 1, were compiled according to a consensus of importance placed on each maneuver as used during five phases of air combat (HELCOM [Ref 7] specifies four phases). A schematic of the 29 maneuvers listed in Table 1 is presented in Figure 5. The development and compilation of these maneuvers were completed in 1978. This computer program allowed a relative comparison of air combat capability between helicopters based upon time required to complete the series of maneuvers. HELCOM III was altered to investigate the effect of dash speed capability.

The five phases of air combat are 1) detection, 2) closing, 3) attack, 4) maneuvering, and 5) disengagement [Ref 7]. The closing phase (2) is combined with the attack phase (3) in HELCOM [Ref 7] to form an initial attack phase. The primary mission of CAS aircraft is to neutralize ground threats. Therefore, emphasis on the first phase is one of detection avoidance. This is significantly aided by hover and low speed agility which are not currently capabilities of Air Force CAS aircraft. The ability to conceal aircraft from enemy radar or visual detection through use of terrain flight increases mission effectiveness by not compromising intentions.

If detection avoidance fails and enemy attack is likely, the closing phase is used to position the aircraft for an attack. Speed and concealment are key elements in any closing phase. Unlike fighter or dedicated counter-air aircraft which use high speeds to close with and attack enemy aircraft, CAS aircraft air combat encounters will be chance encounters at close ranges, requiring little closing. Hover and low speed capabilities enable maximum use of concealment and positioning of the aircraft for attack. Since the mission of CAS is not directed at closing to attack an enemy aircraft, hover and low speed maneuverability are the key to the closing phase rather than high speed dash capability of fighters.

Attack phase is the decisive phase in which weapons are brought to bear on the aerial target. Success of this phase is determined primarily by the weapons characteristics and aircraft maneuverability and agility characteristics.

If weapons characteristics do not permit a quick kill during the attack phase, opponents will enter a maneuvering phase. During this phase aircraft are maneuvered to achieve a weapons solution or to break the opponent's ability to engage. This phase is characterized by rapid maneuvering using both sustained and instantaneous performance attributes.

Disengagement is difficult unless the enemy gives up or is destroyed. Timely disengagement remains paramount to CAS mission effectiveness. According to Reference 7, use of terrain is the key to effecting a one-on-one disengagement. Insufficient dash speed of CAS aircraft may prohibit quick use of nearby terrain features for effecting disengagement, forcing destruction of one aircraft or both. Tactics using mutual supporting aircraft in sufficient numbers may be the only method for CAS aircraft to effect disengagement from air combat situations. Proper mix and configuration of CAS aircraft may serve to deter engagement altogether.

Chapter III

BASELINE AIRCRAFT

3.1 Joint Air Attack Team

Operational necessity to integrate all forces on the battlefield has resulted in merging of CAS assets into an effective fighting team known as JAAT (Joint Air Attack Team). The team consists of Army scout and attack helicopters and Air Force CAS airplanes. This team concentrates firepower quickly while providing increased survivability through mutual support. JAAT serves as an example of battlefield integration of air forces and will be used to investigate aircraft maneuverability and agility. Future battlefields will require even higher levels of integration of air forces which emphasizes the requirement to investigate air combat across the entire spectrum of aircraft designs.

3.2 OH-58D Data Base

The baseline scout aircraft is the OH-58D helicopter (Figure 6). The OH-58D is a conventional single main rotor helicopter with primary design gross weight (PDW) of 3,945 lbs and a maximum gross weight (MGW) of 4,500 lbs for the scout mission. It has a four-bladed, soft-in-plane main rotor system and a two-bladed teetering tail rotor. A single turbine engine provides a maximum of 650 shp at sea level conditions.

3.3 AH-64A Data Base

The baseline attack aircraft is the AH-64A helicopter with a PDW of 14,694 lbs and MGW of 17,650 lbs (Figure 7). The Apache is a single main rotor helicopter with stub wings designed for mounting weapons pods and some lift augmentation. It has four-bladed main and tail rotor systems. Two turbine engines provide a maximum of 1,696 shp each at sea level conditions.

3.4 A-10A Data Base

The baseline CAS aircraft is the A-10A airplane (Figure 8). The A-10A is a single-place, subsonic, light attack aircraft at a mission gross weight of 32,226 lbs and MGW of 46,038 lbs. The aircraft is powered by two General Electric nonafterburning turbofans which provide a maximum uninstalled thrust of 9,275 lbs each at sea level conditions.

Chapter IV

DEFINITIONS

4.1 Maneuverability

Maneuverability is the capability of controlling the vehicle flight path, velocity and altitude in combination. Ability to conduct evasive and offensive actions through maneuvering directly impacts combat effectiveness of any aircraft.

4.2 Agility

Agility is a measure of how quickly the aircraft can be maneuvered. Agility is determined by a combination of performance and handling quality characteristics of the aircraft. Consequently, thrust to weight ratio, control system bandwidth, and control power are indications of the quickness of aircraft maneuvering.

4.3 Combat Effectiveness

Combat effectiveness is the combined effect of survivability and mission effectiveness. Survivability of aircraft in combat is largely determined by the ability to remain concealed from enemy detection or if detected, to use rapid evasive techniques or aggressive air combat maneuvering. Mission effectiveness is the combination of responsiveness (speed) and destructive capability (payload) provided by CAS aircraft. Mission effectiveness is enhanced by improved maneuverability and agility which allow maintaining higher speeds close to terrain and vegetation while delivering ordinance in support of ground forces.

4.4 Nap-of-the-Earth

Nap-of-the-earth (NOE) is flight as close to terrain and vegetation as possible. Speed and altitude are varied to maximize cover and concealment during movement. This flight mode is employed along the forward line of own troops (FLOT) or when in close proximity of known enemy forces.

4.5 Contour

Contour flight is flight at constant airspeed while altitude is varied with terrain. This flight mode generally offers increased speed but sacrifices concealment because higher speeds dictate maintaining increased clearance above obstacles. This flight mode is employed when enemy air defense coverage permits (usually more than 10 km from the FLOT).

Chapter V

RESULTS AND DISCUSSION

5.1 Maneuverability and Agility Analysis

5.1.1 Specific Excess Power (SEP)

Specific excess power is defined as the difference in power available and power required divided by the aircraft gross weight. This parameter provides a measure of aircraft energy state. Excess power may be transformed to generate a climb or to turn the aircraft. Mission effectiveness is enhanced when excess power may also be traded for additional payload. Plots of SEP versus airspeed provide a good snapshot of overall aircraft capability.

Excess power is the single most important design consideration for maneuverability in both fixed wing and rotary wing aircraft. Helicopter design optimization studies have shown that greater installed power is the most weight efficient means to increase excess power [Ref 6]. The lifting force must be repositioned in fixed and rotary wing aircraft to maneuver. Agility is the quickness and precision by which the pilot repositions this lift force. Helicopters directly transfer excess power into greater lift to improve turn or climb performance. Fixed wing aircraft transfer excess power through acceleration to reach the optimum turn speed (V_{MAN}) or climb speed (V_{CL}) to generate greatest lift. Compound helicopter, tilt-rotor, and tilt-wing designs use combinations of direct lift and acceleration to achieve desired performance.

The installed power effects for all JAAT aircraft at mission gross weight are shown in Figure 9 for 4000 ft, 70 deg F. Altitude and temperature were selected to represent operation over average heighth terrain in moderate climates. Airspeed for minimum power corresponds to the maximum point of the SEP curve. The overlay of SEP plots of the three aircraft shows the AH-64A helicopter has the advantage of energy at speeds from hover to 130 KTAS while the A-10A airplane has greater energy capability above 130 KTAS. Figure 9 demonstrates the need for battlefield integration of CAS aircraft for mutual support. The airspeed for minimum power required (airspeed for maximum SEP) indicates the speed at which the aircraft is most maneuverable. It is at this speed that the aircraft may climb quickly to a higher energy state or turn rapidly to gain advantage in air combat. Airspeeds of low SEP (eg. hover and 130 KTAS) are portions of the envelope in which the JAAT team must rely on acceleration, deceleration, or weapons characteristics to gain air combat advantage.

Low SEP for the OH-58D is the result of PDW being 87% of MGW while AH-64A and A-10A aircraft are at 83% MGW. SEP of JAAT aircraft at 87% MGW is presented in Figure 10. Although the OH-58D shows a more favorable energy comparison, the limited dash speed (125 KTAS) severely restricts mission responsiveness when contour flight modes are employed.

Figure 10 also shows the effect of a 10% power available increase for each engine with 10% increase in helicopter transmission capability. At these altitude and temperature conditions the helicopters are limited by transmissions. For pure fixed wing aircraft increased excess power also increases the speed for best maneuvering when Clmax remains unchanged. Therefore, for pure fixed wing aircraft an increase in Clmax must occur to improve low speed maneuverability.

An emerging technology which has integrated fixed wing and rotary wing attributes is the tilt-rotor. Figure 11 shows a comparison of XV-15 data with JAAT aircraft. Current tilt-rotor development is projected to have maximum speeds equalling that of the A-10A airplane while surpassing current CAS aircraft in low speed SEP. Greater SEP and the capability to efficiently use excess power through combinations of rotor tilt makes the tilt-rotor highly maneuverable. Integration of a tilt-rotor configuration in JAAT would enhance combat effectiveness through more complete mutual support and quicker mission response.

Limiting factors for excess power vary with aircraft design. Transmission and gearbox limits may prevent use of maximum installed power on helicopters. In terrain flight or air combat maneuvering, greater excess power may only be required in transient intervals of less than 10 seconds. By incorporating transmission capability within a transient rather than a continuous constraint, aircraft weight can be minimized while achieving improved ATAC capability. Fixed wing aircraft are limited by Clmax at speeds lower than maneuver speed and by thrust to weight at high speeds. Aircraft designs which fall between pure helicopters and pure airplanes take advantage of direct lift concepts to reduce the low speed Clmax limit and fixed lifting surfaces to reduce the limits imposed by transmissions and gear boxes.

5.1.2 Sustained Turn Performance

The turn performance of aircraft may be classified as sustained or instantaneous. Sustained turn performance occurs when energy remains constant in the turn. Altitude is neither gained nor lost.

Sustained turn performance is important for terrain flight when survivability depends upon remaining close to terrain and vegetation. Results of impacting a tree can be as costly as being destroyed by a missile.

Turn performance is obtained by tilting the lift force in the direction of turn. Excess lift that can be developed at a given airspeed is a measure of the sustained turn performance. HELCOM uses the excess power available within limits of Clmax at each given flight condition to compute sustained turn performance. Excess power depends on installed power, power losses due to mechanical efficiencies and power extraction, induced power, parasite power, and in the case of rotorcraft, profile power. Maximum sustained load factor is computed by increasing aircraft weight until power required equals power available or until Clmax is reached.

Sustained turn performance for the JAAT aircraft are shown in Figures 12 to 15. The maneuver speeds are 50 KTAS for the OH-58D; 85 KTAS, AH-64A; and 260 KTAS, A-10A. Sustained turn capability (Figure 13) is shown by the excellent turn capability afforded by vertical flight and good yaw control power. Analysis of fighter designs showed that a 5 deg/sec (approximately 25%) better sustained turn rate than the opponent provides a 2:1 advantage in air combat [Ref 14]. A 10% power available increase per engine resulted in 4 deg/sec (14%) increase in sustained turn rate at 35 KTAS and 1 deg/sec (5%) increase at best maneuver speed for the AH-64A helicopter. A 10% power increase for the OH-58D (single engine aircraft) resulted in a slight reduction to an already small turn radius.

Limiting factor for sustained turns is excess lift. For helicopters this equates to excess power. For all other designs a combination of Clmax and excess power establishes maximum sustained turn performance. The effect of 20 degree flaps and 20 degree flaps plus 10% additional power shows the improvement attained with fixed wing configurations (Figure 14). Figure 15 emphasizes the need for high lift devices to improve low speed turn capability. One method is to tilt engine nacelles for vertical thrust similar to the tilt-rotor concept.

5.1.3 Instantaneous Turn Performance

Instantaneous turn performance occurs within aircraft structural limits or buffet boundary and typically results in deceasing the energy state of the aircraft.

Instantaneous turn performance is important for defensive maneuvering because it allows breaking enemy lock by jinking maneuvers and allows pilots to remain unpredictable in combat.

The structural or buffet boundary limits establish the instantaneous turn performance. HELCOM uses the established maximum load factor as determined by Clmax and the structural load limit to establish instantaneous turn performance. Helicopter transient limit is established by maximum transient blade loading. Values for the OH-58D maximum transient blade loading coefficient were estimated.

Instantaneous turn performance is shown in Figures 16 to 19. Corner speed for maneuvering is established by intersection of the lift limit and structural limit. Best instantaneous maneuver speeds are 40 KTAS for the OH-58D and AH-64A and 300 KTAS for the A-10A. Acceleration or deceleration to the maneuver speed must be accomplished to take full advantage of maximum instantaneous turn capability.

Limiting factor is primarily structural. Increased structural limits for fixed wing and rotary wing aircraft results in increased speed required for best instantaneous maneuvering. Figure 18 depicts the effects for the A-10A airplane. Lift increases to reduce instantaneous maneuvering speed cannot be accomplished by simple flaps due to flap structural limits (Figure 19). Vectored thrust may offer the best solution for improvement to fixed wing instantaneous turn performance. Wing lift to reduce rotor loads may offer similar results for rotary wing designs.

5.1.4 Acceleration

Acceleration, the ability to change airspeed, is critical to survivability and mission effectiveness. The NOE environment presents a constantly changing array of situations to the pilot with very little forewarning.

Acceleration is achieved through tilting the rotor tip path plane in helicopters. Fixed-wing aircraft acceleration is accomplished with direct application of additional engine power. Designs within these two ends of the spectrum utilize a combination for maximum effect. HELCOM uses excess power within the constraints of longitudinal normal force limits to compute longitudinal acceleration.

Limiting factor for helicopter acceleration is a practical pitch attitude which can be used NOE. Airplane and other designs are limited by excess thrust available and engine response time.

JAAT aircraft acceleration capabilities are presented in Figures 20 to 22. Helicopter acceleration is very high near hover conditions and rapidly diminishes. The airplane shows only a modest acceleration decrease but the high weight and drag configuration of the A-10A limits maximum acceleration capability. Acceleration capability presented in Figure 21 represents two dimensional aircraft agility at best maneuver speed for each type aircraft. Increased power available effect on longitudinal acceleration is shown in Figure 22. Designs which use power for acceleration show a marked improvement throughout the speed range. Designs which must tilt additional vertical thrust to achieve longitudinal acceleration show diminishing effects as speed increases.

Acceleration capability is improved by increasing longitudinal thrust. At the helicopter end of the spectrum a tilt mast design which reduces the high pitch attitude requirement is one method of improvement. Other devices for increasing longitudinal thrust are propeller, fan, or convertible engine. NOTAR is an emerging technology which provides antitorque thrust without use of a conventional tail rotor. Modification to the NOTAR design concept may eventually evolve to produce additional longitudinal thrust in forward flight. For designs ranging from compound helicopter to fixed wing, increased acceleration is gained by increased thrust to weight and faster engine response. Improvement can also be obtained by reducing drag through streamlined fuselage and internally carried ordinance.

These changes directly conflict with any improvements desired in deceleration capability.

5.1.5 Deceleration

Deceleration capability is of equal importance to acceleration in terrain flight. Rapid deceleration from any speed enhances survivability by allowing maximum use of cover and concealment. Deceleration is vital to air combat when the encounter occurs at speeds greater than best maneuver speed.

Deceleration is obtained by tilting the rotor tip path plane aft and reducing power in the case of helicopters. Power reduction combined with speed brakes and pitch out maneuvers are used for fixed wing aircraft decelerations. High pitch attitudes facilitate rapid decelerations for all aircraft types but have not been considered in this analysis. Level attitude decelerations enable the pilot to maintain visual contact with terrain and obstacles or enemy aircraft. In actual practice a combination of deceleration techniques is used but this analysis considered only the level deceleration. HELCOM computes level deceleration based upon the power required for level flight.

JAAT aircraft deceleration capabilities are presented in Figures 23 to 25. The high drag configurations of helicopters show a significant advantage throughout the airspeed range. The A-10A, as most fixed wing combat aircraft, incorporates a speed brake which can be used to enhance deceleration as shown in Figure 24. Deceleration capabilities are presented in Figure 25 at the best maneuver speed for the AH-64A and the A-10A. The helicopter shows a greater level attitude deceleration capability than the fixed wing at normal accelerations greater than 1.8 g. During level, 1 g flight the helicopter must use high pitch attitudes to achieve decelerations available to fixed wing aircraft equipped with speed brakes.

Deceleration capabilities can be improved through forms of speed brakes, spoilers, or vectored lift devices. Ability to tilt the helicopter rotor aft without changing fuselage attitude would improve both terrain flight and air combat capabilities.

ATAC studies addressed both the use of rotor mast tilt and speed brakes for helicopters. Tilt-rotor has the desirable ATAC capability of rearward mast tilt. Airplane designs have continued to investigate vectored thrust which can enhance deceleration as well as lift.

5.2 Air Combat Maneuvering

Helicopter M&A parameters calculated in HELCOM I were used to compute the time required to execute the combat maneuvers in HELCOM III. The results are presented in Table 2 for current JAAT helicopters and their predecessors. An improvement of 10% to 22% over original CAS helicopters has been achieved through improved performance capability. Not included in Table 2 were improvements in weapons, targeting, and visual systems capabilities and handling qualities improvements. HELCOM III does not accommodate analysis of conventional fixed wing aircraft designs as evidenced by the maneuver summary (Table 1).

5.2.1 Design Implications for ATAC

Effect of blade loading is shown in Figure 26. HELCOM III quantifies the positive effect reduced blade loading has on maneuverability and agility. Approximately 2 seconds ATAC time savings per percent decrease in blade loading is shown for variations of an AH-64A helicopter at 14,733 lbs.

Effect of power available is shown in Figure 27. HELCOM III quantifies the positive effect of increased power available discussed in paragraph 5.1.1. ATAC time savings of 5 seconds per percent increase in power available is shown for variations of an AH-64A helicopter at 14,733 lbs.

Effect of aircraft gross weight is shown in Figures 28 and 29. ATAC capability of JAAT helicopters is diminished with increasing gross weight but remains significantly better than the predecessors. These comparisons do not reflect weapons, targeting, visual systems, and handling qualities improvements which further enhance ATAC capability of the current scout and attack helicopters.

5.2.2 Sensitivity Analysis

Sensitivity to maximum dash speed was analyzed by varying dash distance requirement in maneuver 1. Maneuver 1 required a dash for 10 km. Forward area refueling points are normally located 25 km behind initial battle positions. Additionally, CAS aircraft may be required to respond to threat penetrations anywhere along a 50 km Division Front. Figure 30 shows the result of varying distance from 0 to 75 km. At 10 km maneuver 1 represents only about 10%-15% of the total time and dash speed is relatively unimportant. Increasing distances correspond to offensive CAS for deep penetration missions or to defensive CAS against enemy penetrations anywhere along the Front. Importance of having an aircraft capable of responding quickly to CAS or ATAC mission is demonstrated by the increased percent of ATAC time required during initial vectoring. High dash speed is important for attaining tactical advantage but is of little significance once engaged in an ATAC fight [Ref 15].

5.3 Operational Considerations

HELCOM is a tool to model aircraft for a quick look at relative aircraft capabilities in the arena of air combat. Approximations have been made to speed calculations without severe loss of accuracy in performance estimations. Although performance may be considered the primary factor in determining ATAC capability, operational considerations greatly impact air combat capability. Pilot training and experience, aircraft detectability and physical constraints, aircraft weapons, target acquisition capability, and aircraft handling qualities are factors which effect the use of aircraft performance capabilities estimated by HELCOM. Aircraft design must address each of these considerations in relation to the threat environment. Relevance of each consideration is guided by combination of perceived threat and mission requirements.

The certainty of ATAC within 300 meters of the terrain requires CAS pilots be trained for the additional counter-air role. Design should continue to emphasize standardization and total system integration to reduce pilot training and workload requirements. Communications, warning system, target acquisition, and weapons delivery design requirements derived from terrain flight experience are applicable to air combat. Pilot training must include increased use of simulation to provide a means to exercise the pilot's ability to integrate these systems during various combat scenarios. NOE flight training has provided initial development of pilot skills for utilizing the attributes of maneuverability and agility in air combat.

Aircraft detectability parameter includes factors of size, shape, and color. Shape is constrained by functional and aerodynamic requirements and color by environmental considerations. Therefore, size becomes a primary design variable in minimizing detectability. Aircraft should be as small as practicable. Tests and experience have proven the smaller aircraft is more difficult to acquire even at close ranges. Design optimization could be formed with size constraints imposed as a function of range. ACT IV testing showed an advantage, even at close range, for the Bell 406 Combat Scout (OH-58D airframe) simply due to its size [Ref 16]. The armed OH-58D provides a good example of improvement in performance, target acquisition, and weapons capabilities within a small airframe size.

A primary physical constraint is pilot field of view (FOV). The largest available FOV is desireable but remains constrained by structural requirements. Ground based simulation has verified that a large FOV is imperative [Ref 17]. Helicopters usually possess the unique capability to view downward through a lower windshield or chin bubble which aids in terrain flight and air combat. Efforts to remove FOV blockage in overhead quadrants should reflect similar unrestricted viewing found in fighter aircraft designs. Threat CAS helicopters normally operate at higher speeds and consequently; at contour flight altitudes. This fact emphasizes a design priority for improving overhead FOV. The efforts to improve level acceleration and deceleration capability improve FOV by requiring smaller fuselage attitude changes.

Aircraft weapons considerations include type, caliber, rate of fire, and fire control system. Aircraft should be designed capable of carrying antiair missiles and guns.

Missiles provide air-to-air capability for targets greater than 500 m with significant infrared signatures while guns provide close in coverage for the most probable engagements. Commonality of mounting permits configuring aircraft based upon the combat situation. High rate of fire is required for air targets which places an additional constraint on selection of the type of gun. Fire control system must not require significant pilot attention during the brief encounter. Weapons systems must be integrated to assist the pilot and provide tactical flexibility.

Target acquisition system includes long range warning, mid range identification and close in tracking. Adequate warning is essential since speed and maneuver alone are unable to defeat modern missiles [Ref 18]. Each of the three tiered system should be optimized and integrated to maximize mission effectiveness.

Handling qualities, as constrained by control power and margins, is the measure of aircraft agility [Ref 5]. Handling qualities of aircraft determine how well the pilot may integrate performance capabilities of the aircraft with weapons system capabilities. Within the NOE environment at least a 3 g capability is required for missile evasion. Pilots will not be likely to utilize higher normal forces in the NOE environment but higher lateral force levels could be beneficial in low speed flight. The capability to yaw the aircraft (point the nose) at high speeds is desirable because it allows quicker engagements. This capability requires a large sideslip envelope which places greater stresses on the fuselage and on the drive train for tail rotor configurations. NOTAR is an emerging technology that may provide this greater flight envelope.

Chapter VI

CONCLUSIONS

HELCOM I can be used to investigate both helicopter and fixed wing aircraft. Energy/force balancing procedures provide a good approximation of performance capabilities which determine maneuverability and agility parameters.

Integrating all air forces on the battlefield to maximize combat effectiveness suggests an integrated approach be used to evaluate technological options available to meet CAS mission requirements.

Future CAS aircraft designs should continue to emphasize large excess power available with capability to convert excess energy to lift or acceleration. CAS aircraft ATAC improvement can be gained through efforts to increase transient power capability.

Future CAS aircraft should be designed with a counter-air configuration. Political funding of a dedicated counter-air vehicle is unlikely until future armed conflicts verify this perceived need. An emerging technology capable of filling this role is a tilt-rotor concept. This versatile concept possesses maneuverability and agility surpassing current CAS aircraft.

Chapter VII

RECOMMENDATIONS

HELCOM III should be further validated and revised. Design options which span the spectrum from helicopters to fixed wing aircraft should be included. Maneuvers should be adjusted to reflect current training and doctrine. Standardization of scenarios should be mission oriented and reflect low altitude air warfare in addition to delineating between fixed wing and rotary wing aircraft.

Computer modeling should incorporate calculation of stability derivatives. This computation would allow agility to be more completely defined by including both thrust to weight and control power considerations.

Additional aircraft models should be added to the data base of HELCOM I. Compound helicopter (eg. Cheyenne), tilt-rotor (eg. Osprey), and fan-in-wing designs would facilitate air combat studies for determining relative merit of alternate configurations.

Table 1. HELCOM III Maneuver Summary

Maneuver	Description
1	Accelerate from hover to maximum level flight speed and fly 10 KM
2	Climb a 500 FT hill of 30 deg slope
3	Descend a 500 FT hill of 30 deg slope
4	Climb a 500 FT hill of 20 deg slope
5	Descend a 500 FT hill of 20 deg slope
6	Climb a 500 FT hill of 10 deg slope
7	Descend a 500 FT hill of 10 deg slope
8	Traverse 2 KM of low rolling hills of 500 FT
9	Perform 5 popup maneuvers through 50 FT
10	10 vertical turns through 180 deg
11	Accelerate and normal stop in 500 M., 5 times
12	Accelerate and level stop in 500 M., 5 times
13	Fly through a 500 M. course comprising a continuous series of 100 FT radius turns
14	Fly through a 1000 M. course comprising a continuous series of 400 FT radius turns
15	Fly through a 2000 M. course comprising a continuous series of 2000 FT radius turns
16	Fly through a 500 M. course containing intermittent 50 FT radius turns
17	Fly through a 1000 M. course containing intermittent 150 FT radius turns

Table 1. HELCOM III Maneuver Summary Continuation

Maneuver	Description
18	Fly through a 2000 M. course containing intermittent 400 FT radius turns
19	Accelerate from hover and fly 1 KM at maximum level flight speed
20	Maximum turn through 360 deg from maximum speed to 40 KTAS
21	Accelerate from 40 KTAS to 100 KTAS
22	10 maximum turns through 60 deg from 100 KTAS
23	10 maximum turns through 120 deg from 100 KTAS
24	10 maximum turns through 180 deg from 100 KTAS
25	3 accelerations from airspeed reached in 60 deg turn to 100 KTAS
26	3 accelerations from airspeed reached in 120 deg turn to 100 KTAS
27	3 accelerations from airspeed reached in 180 deg turn to 100 KTAS
28	Climb through 1000 FT at best climb speed
29	Dive through 1000 FT at 100 KTAS at steepest angle possible

Table 2. JAAT ATAC Capability

	Scout		Attack	
Aircraft	OH-58A	OH-58D	AH-1S	AH-64A
ATAC Time (sec)	1616	1253	1311	1178
Gross Weight (lbs)	2,640	3,945	8,300	14,733
Percent of Maximum Gross Weight	87	87	83	83
Blade Loading (lb/ft^2)	69.2	62.9	83.8	87.7
Change in ATAC Time	22%		10%	

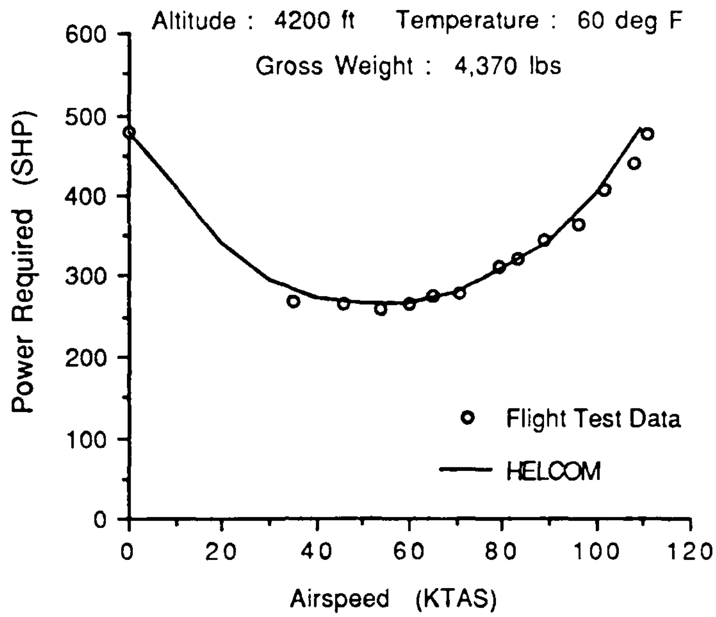

Figure 1. OH-58D Performance Comparison

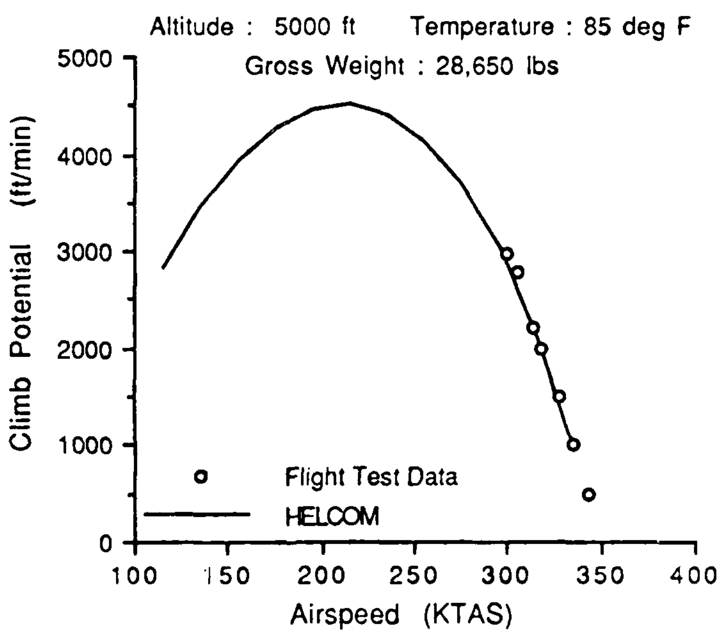

Figure 2. A-10A Performance Comparison

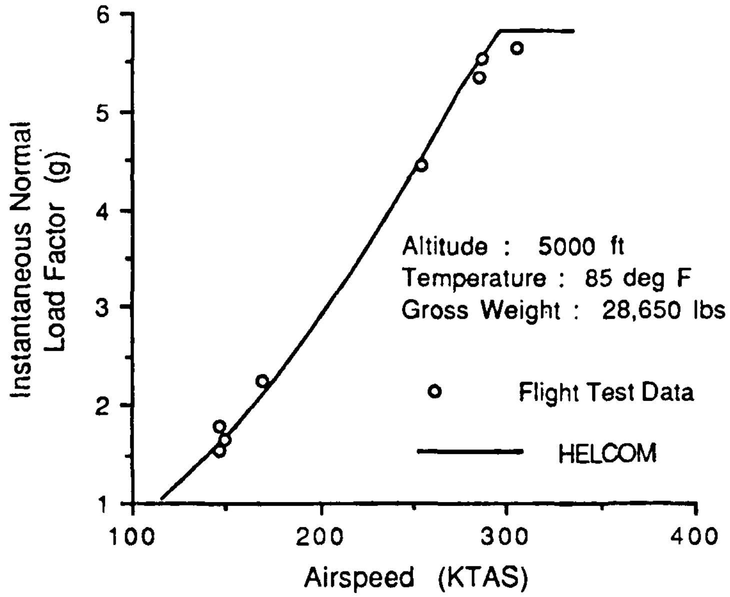

Figure 3. A-10A Instantaneous Acceleration

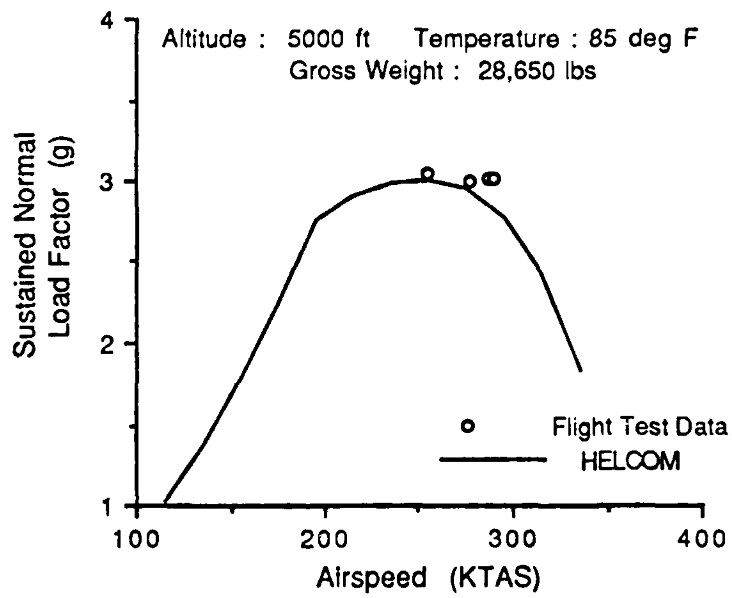

Figure 4. A-10A Sustained Acceleration

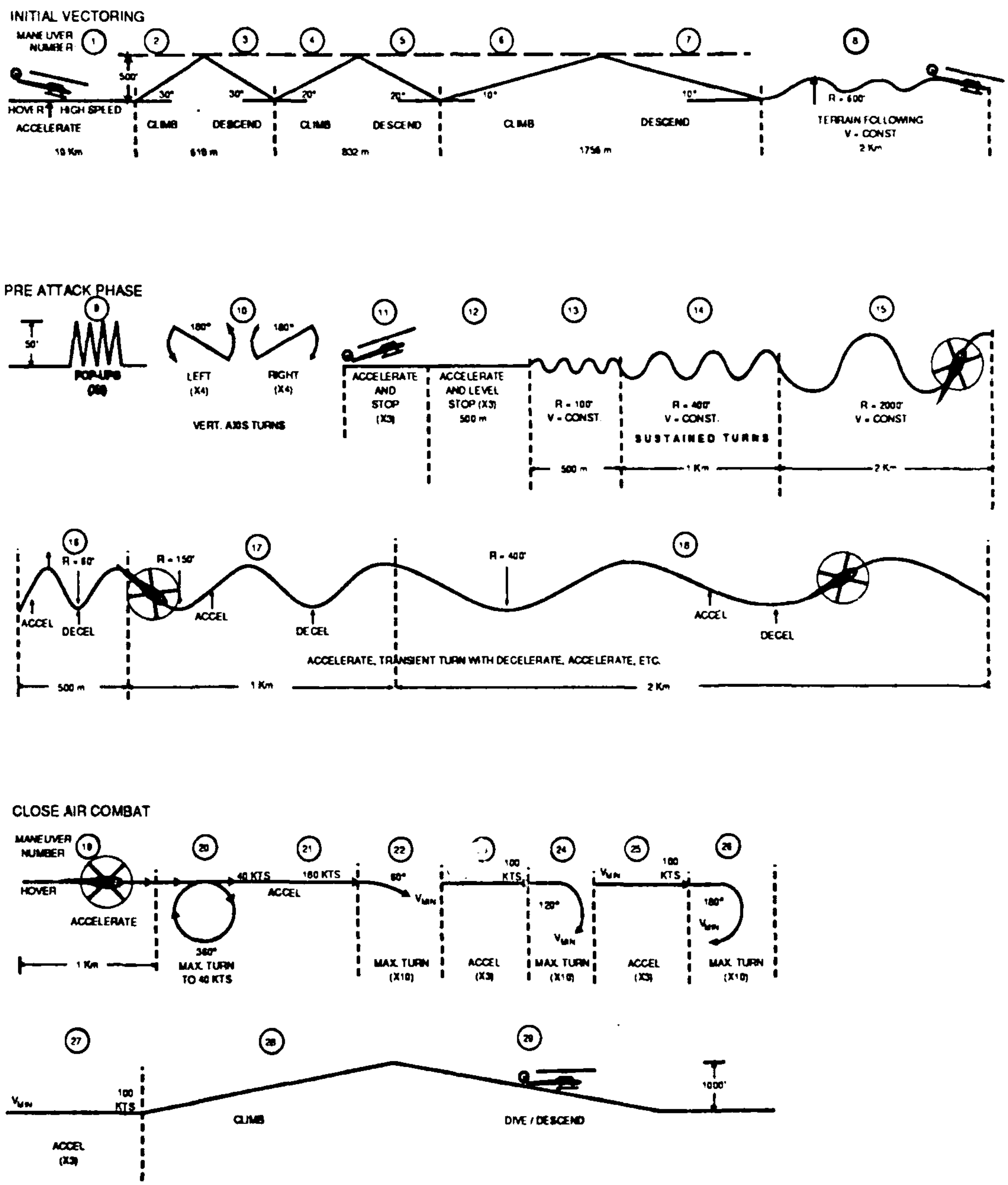

Figure 5. HELCOM III Maneuver Schematic

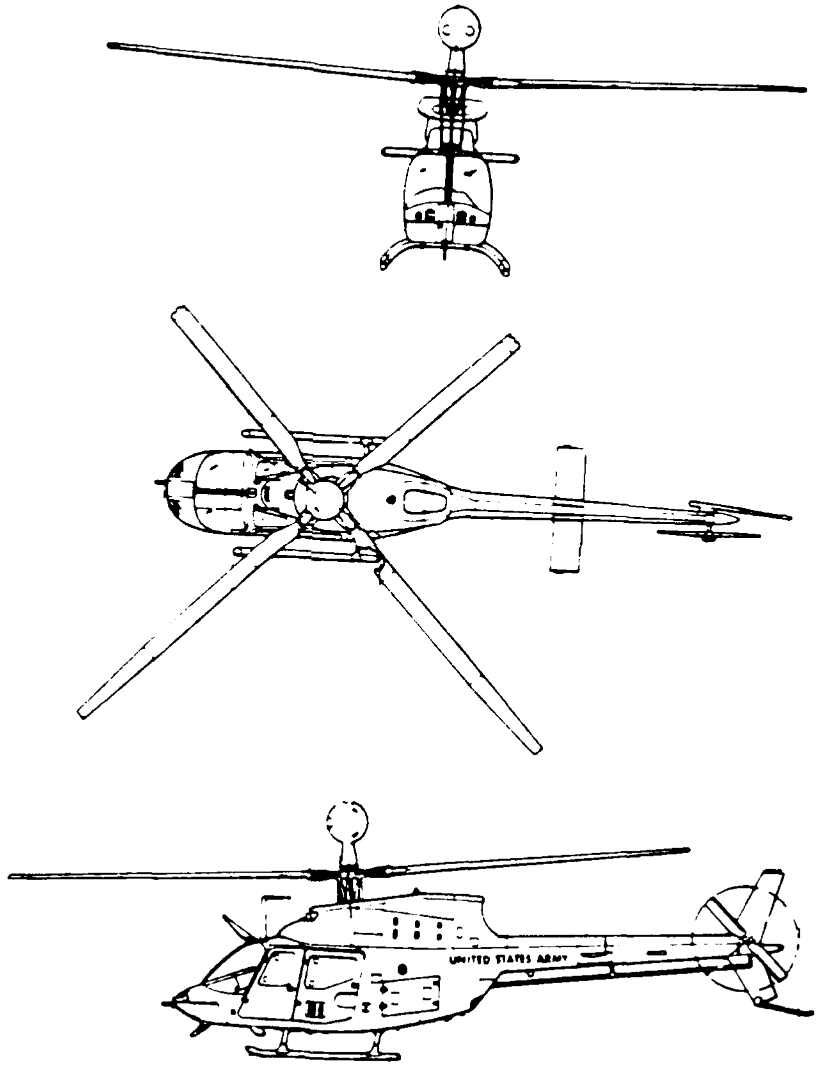

Figure 6. OH-58D Helicopter

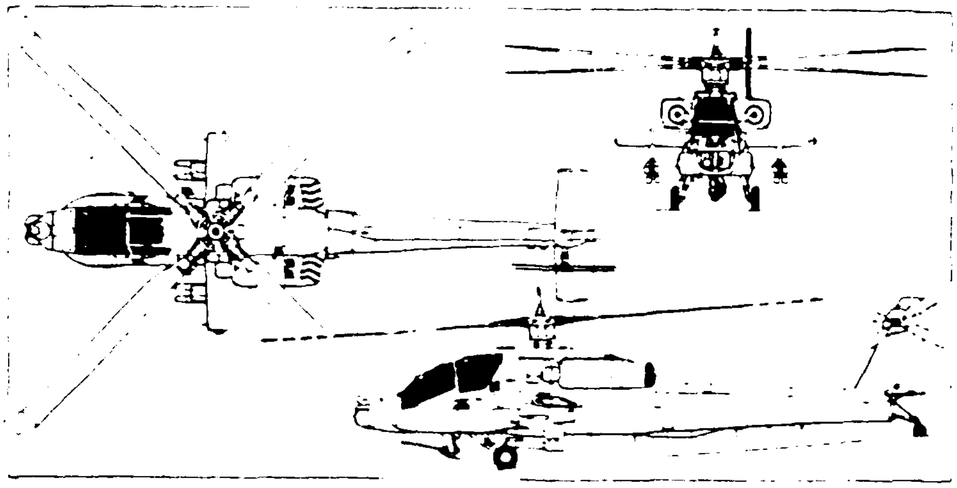

Figure 7. AH-64A Helicopter

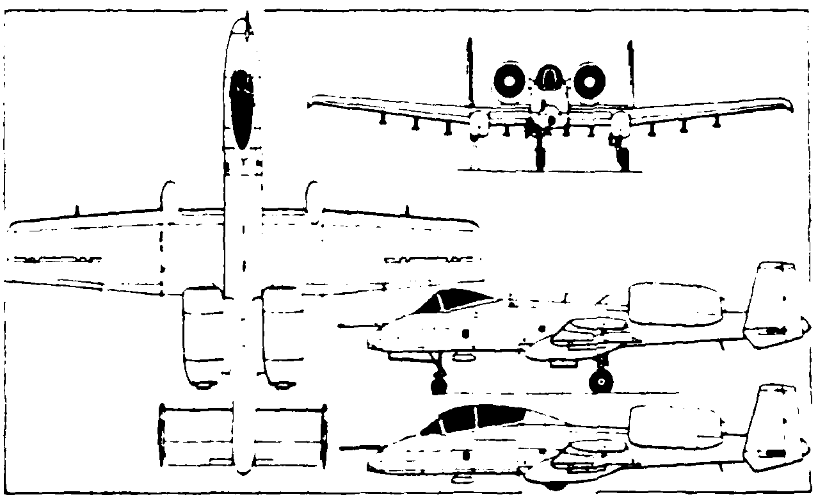

Figure 8. A-10A Airplane

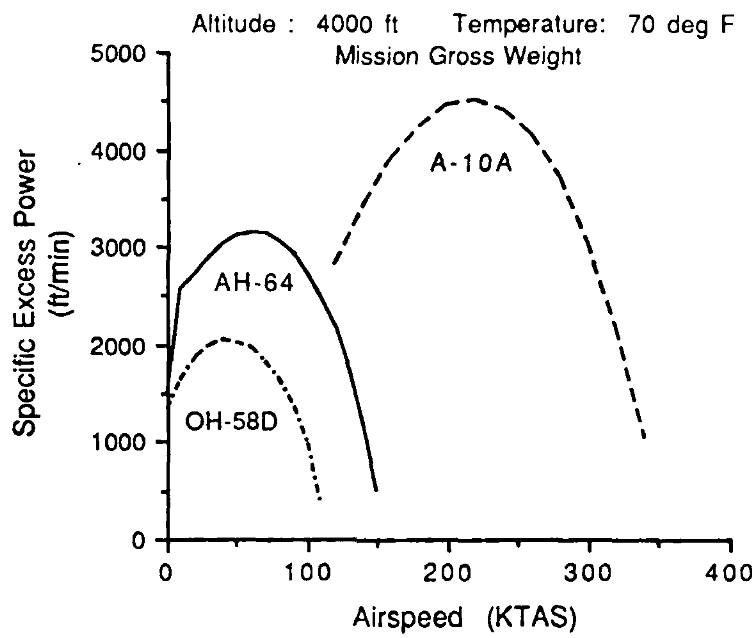

Figure 9. Specific Excess Power

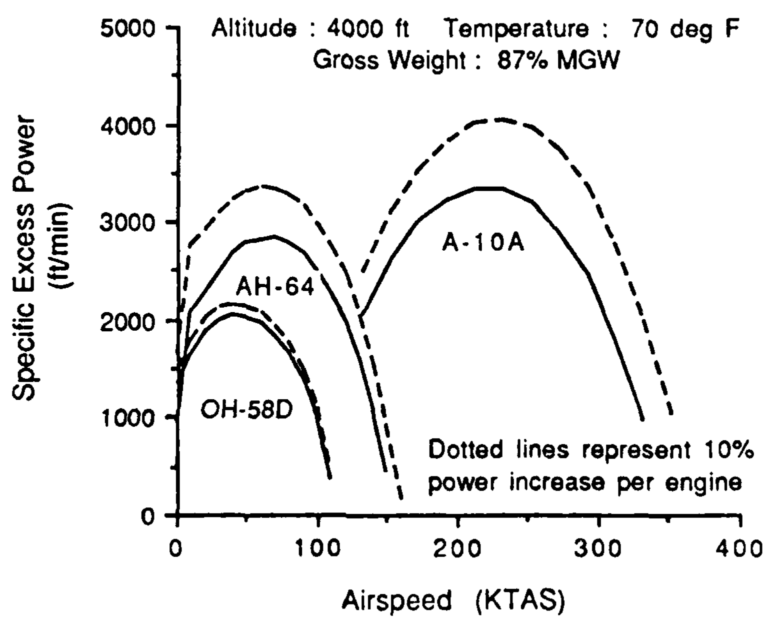

Figure 10. Power Available Effect

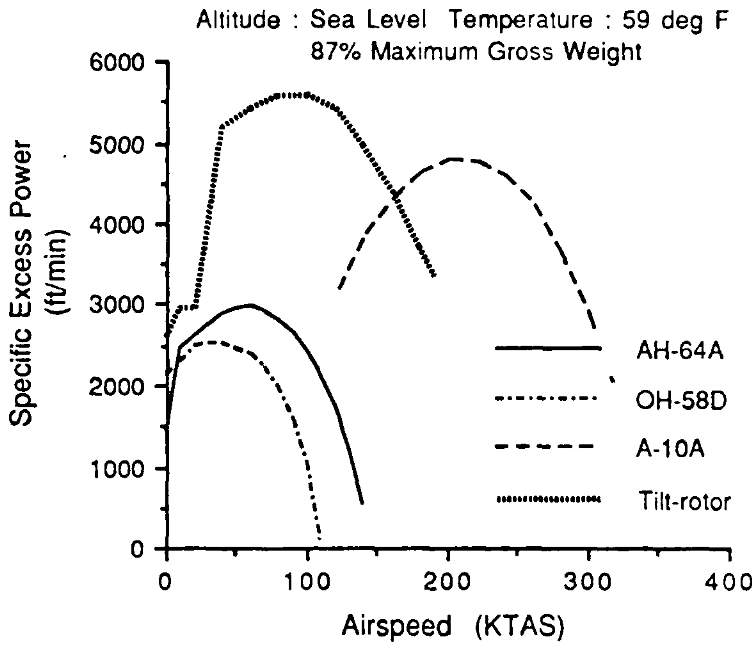

Figure 11. Tilt-rotor Comparison

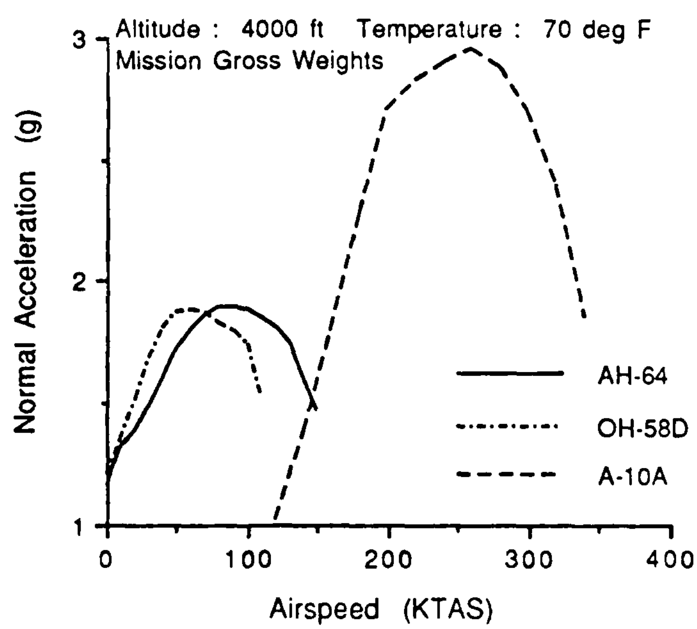

Figure 12. Sustained Normal Acceleration

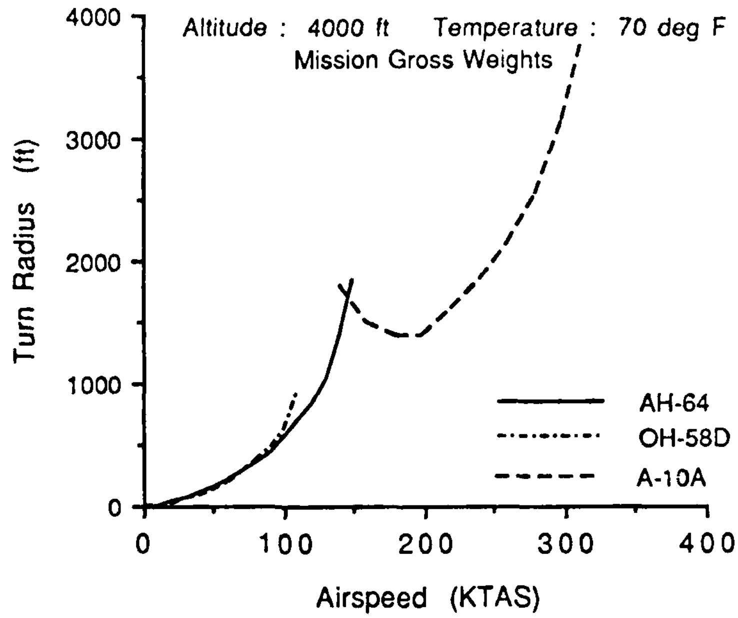

Figure 13. Sustained Turn Radius

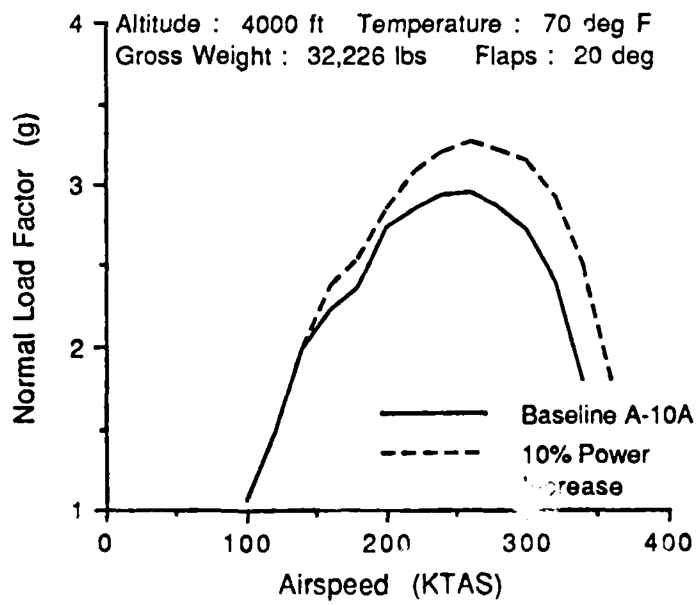

Figure 14. Power & Flap Effect

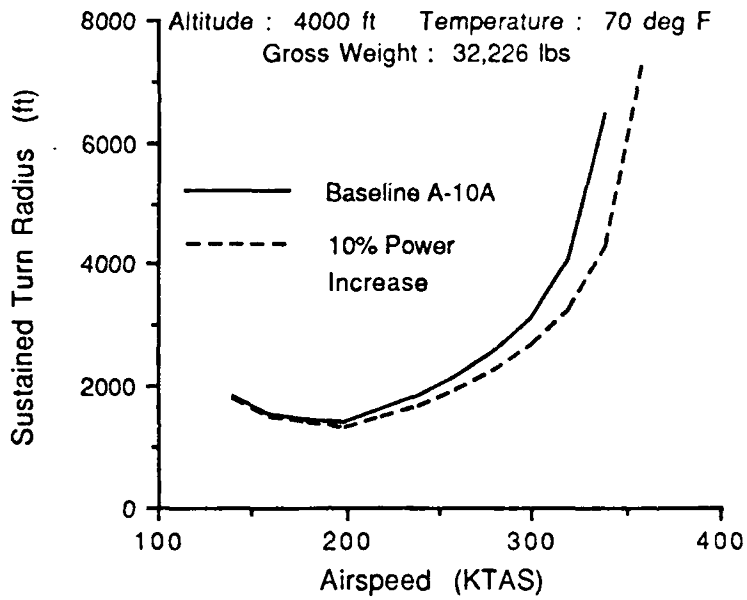

Figure 15. Power Effect on Turn Radius

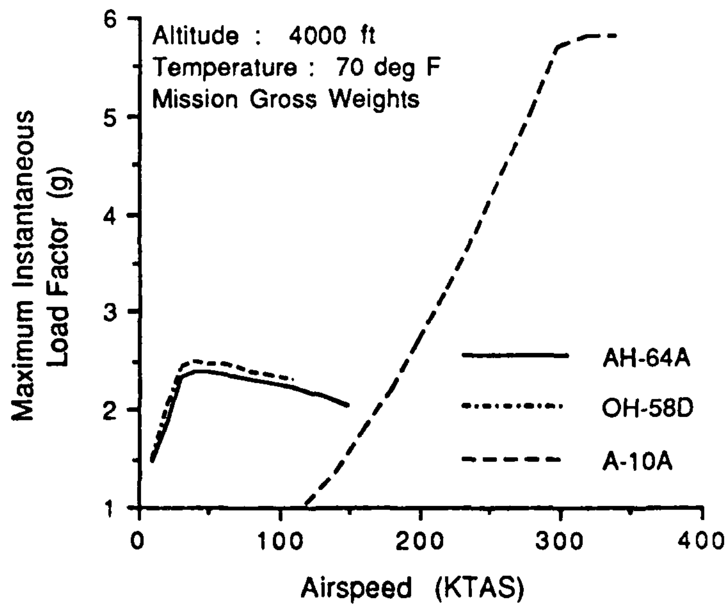

Figure 16. Instantaneous Normal Acceleration

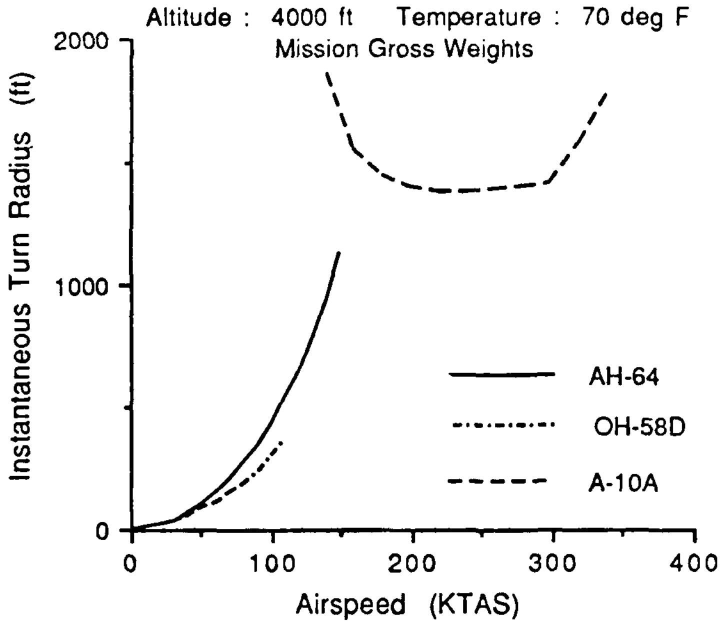

Figure 17. Instantaneous Turn Radius

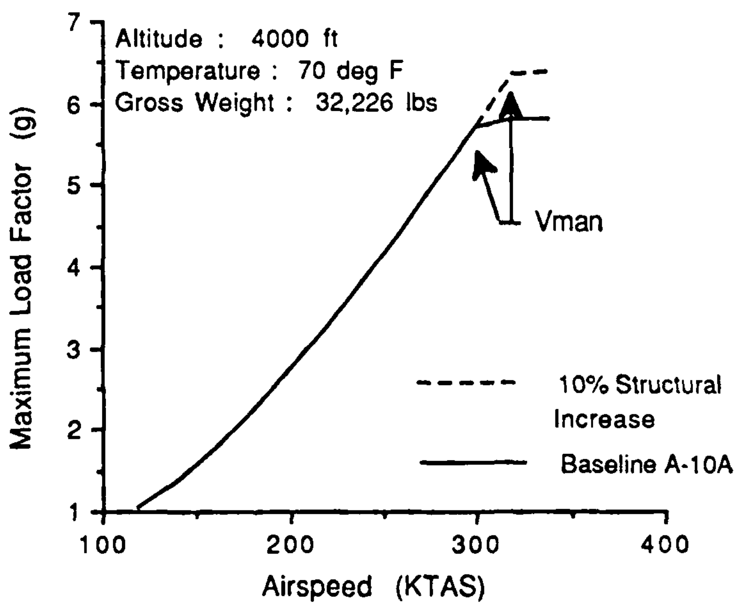

Figure 18. Structural Limit Effect

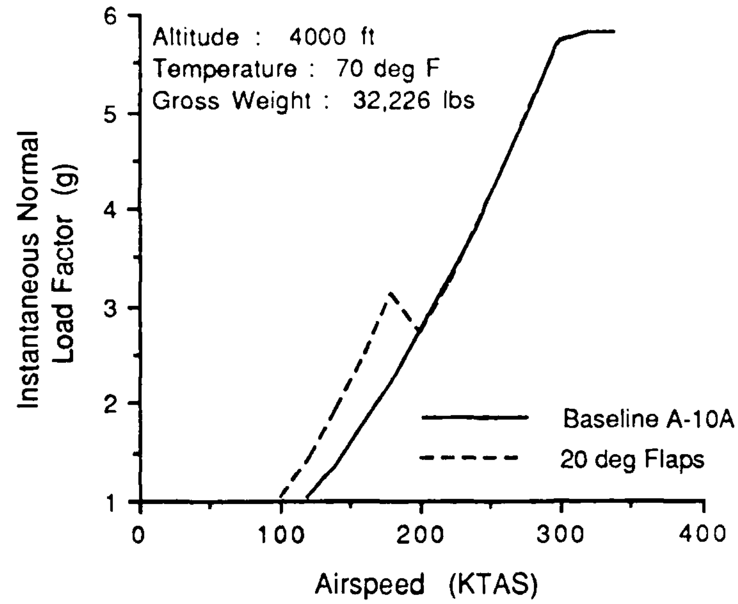

Figure 19. Flap Effect on Normal Acceleration

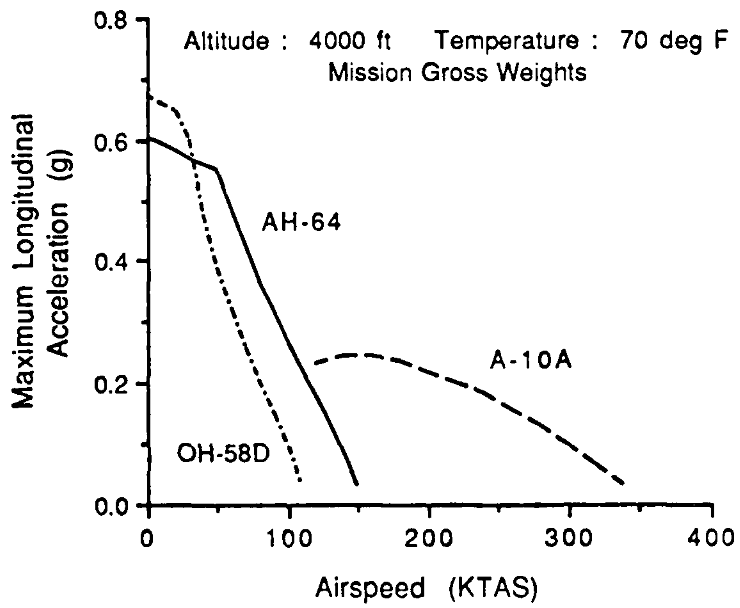

Figure 20. Longitudinal Acceleration

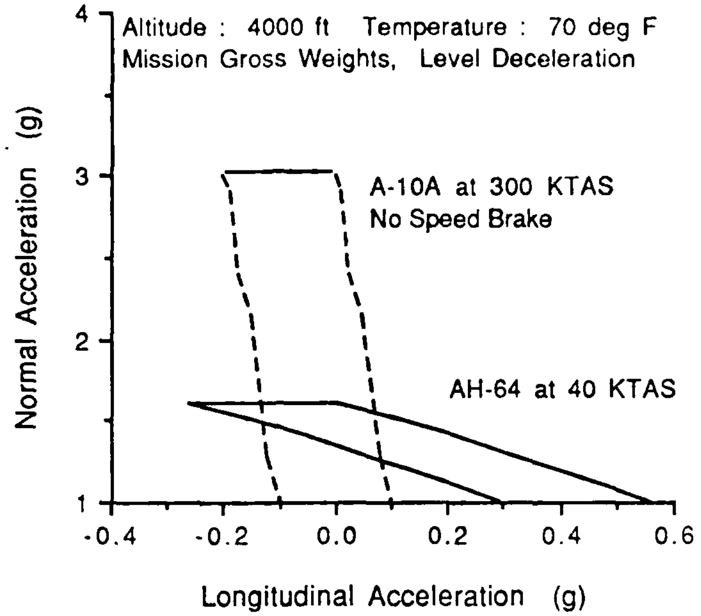

Figure 21. Maneuver Speed Sustained Capability

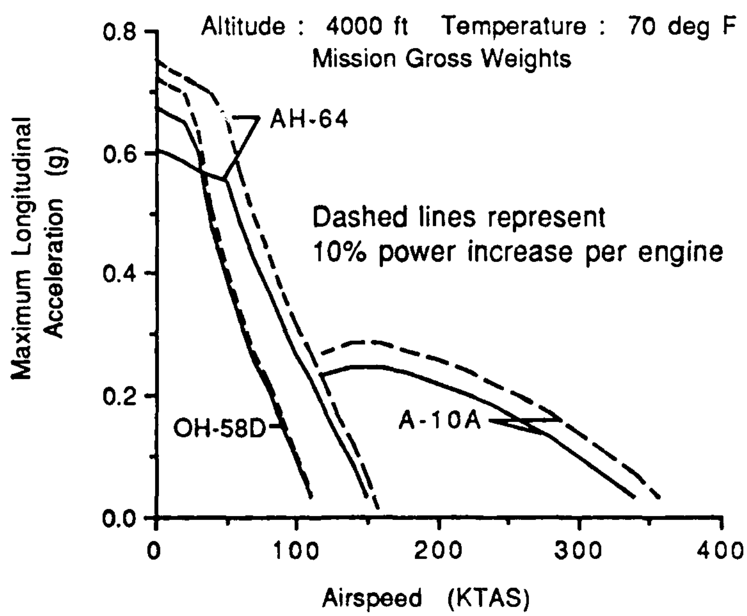

Figure 22. Power Effect on Longitudinal Acceleration

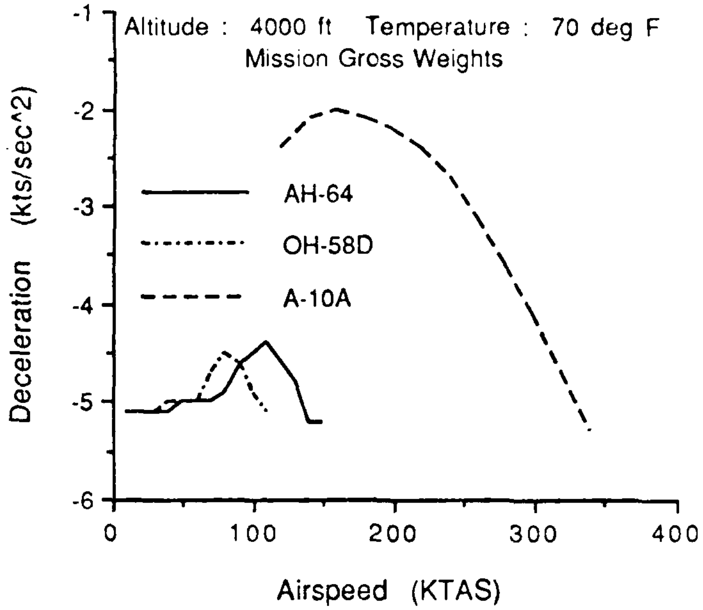

Figure 23. Level Attitude Deceleration

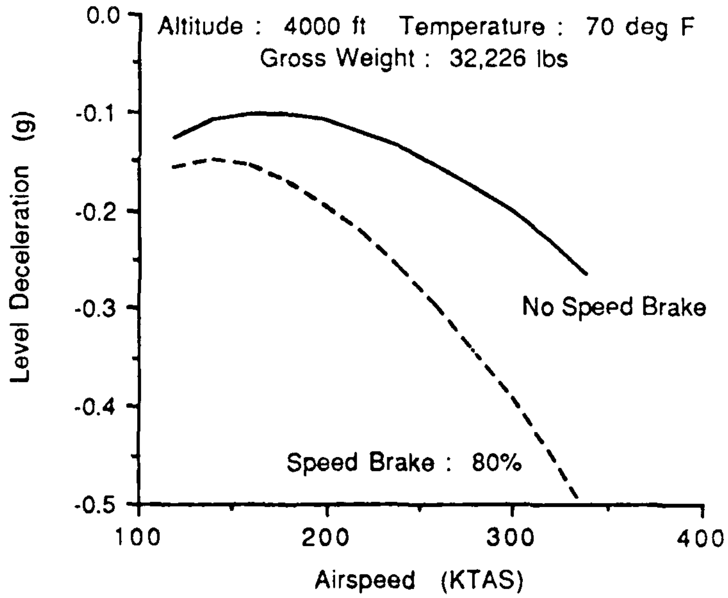

Figure 24. Speed Brake Effect

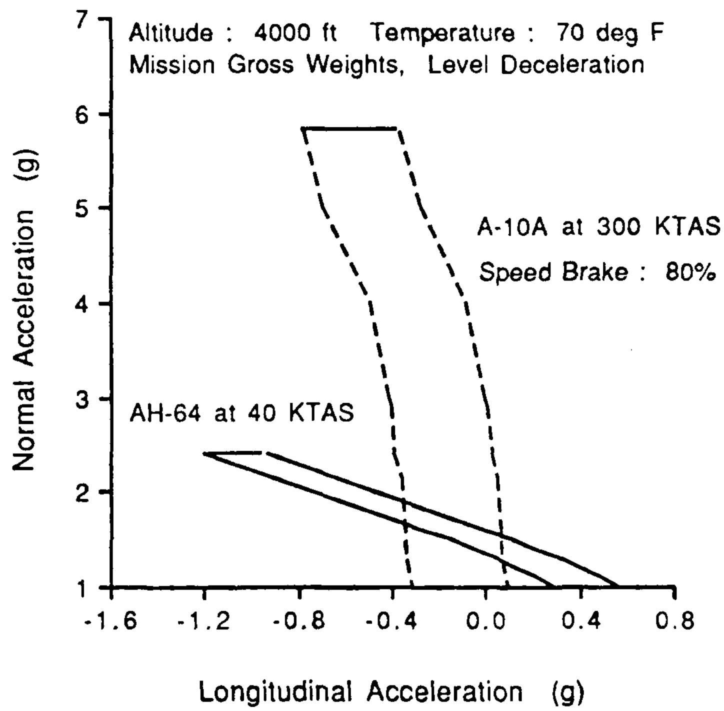

Figure 25. Maneuver Speed Instantaneous Capability

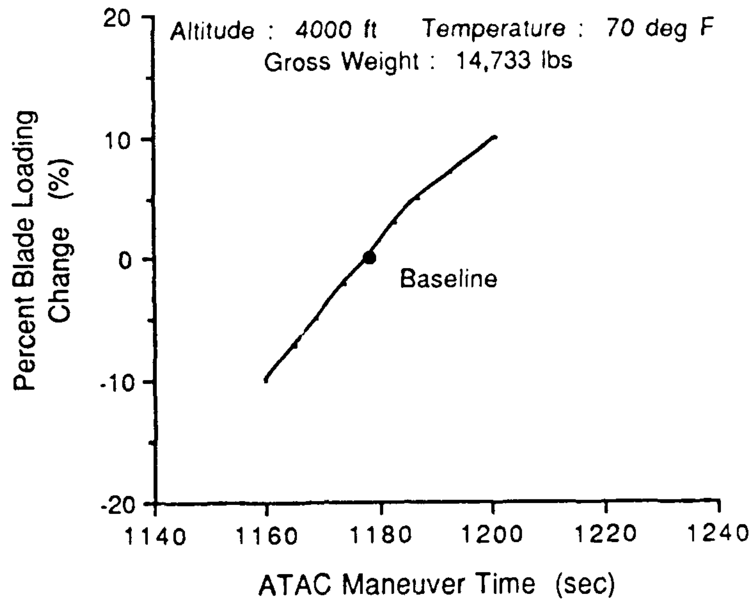

Figure 26. Blade Loading Effect on AH-64A ATAC

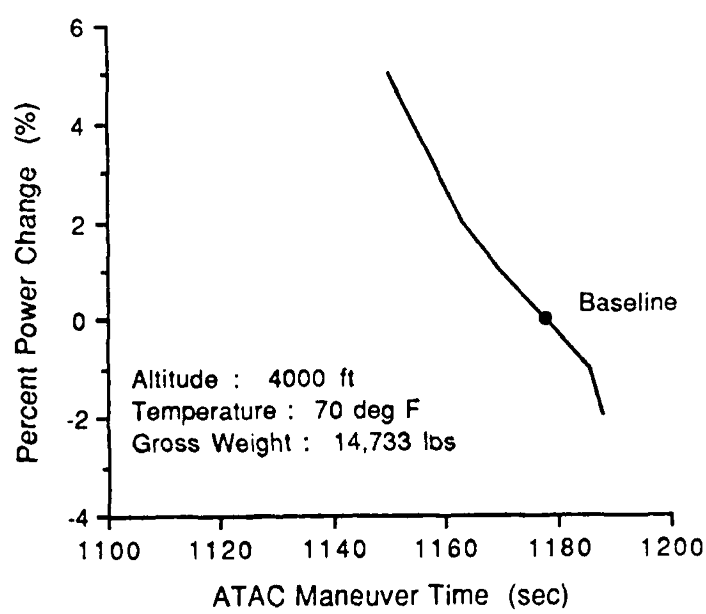

Figure 27. Power Effect on AH-64A ATAC

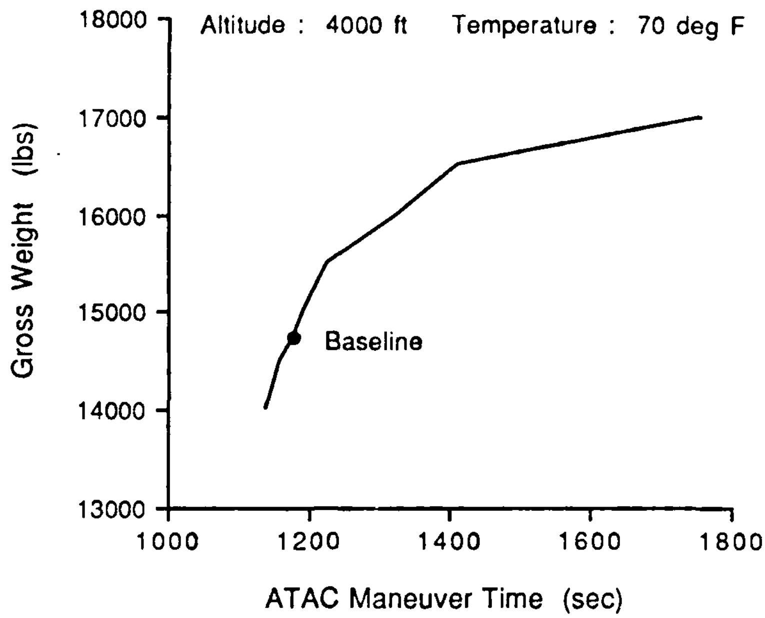

Figure 28. Gross Weight Effect on AH-64A ATAC

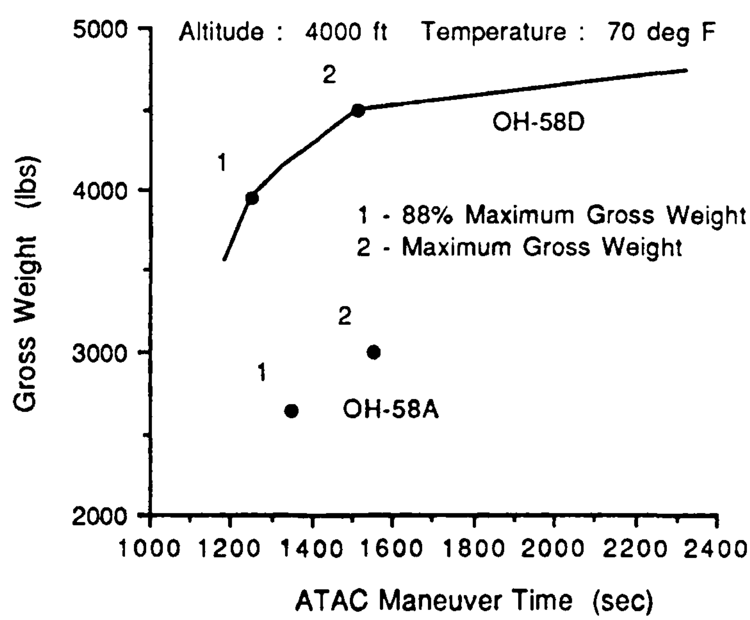

Figure 29. Gross Weight Effect on OH-58D ATAC

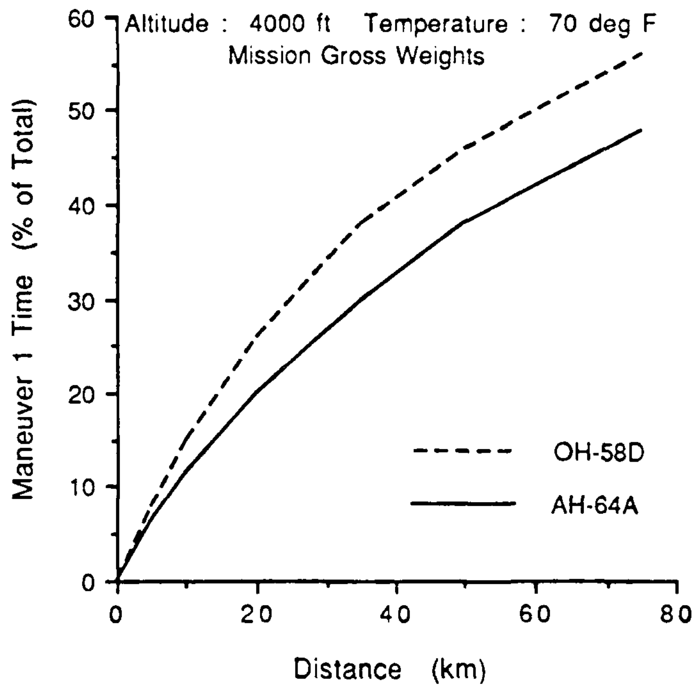

Figure 30. Dash Distance Sensitivity

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